

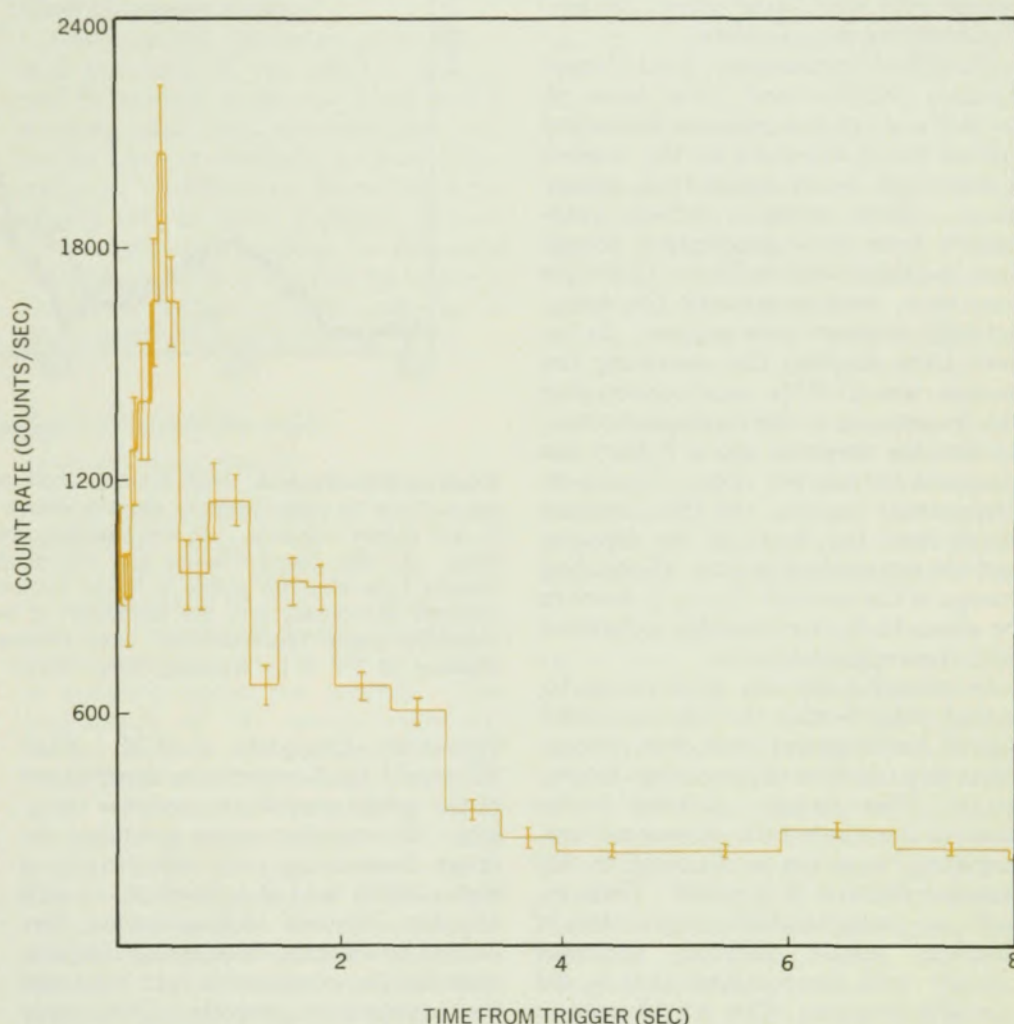
search & discovery

Many models proposed to explain cosmic gamma-ray bursts

The various wavelength regimes of observational astronomy seem to generate their maximum excitement when rapid time-varying phenomena are first observed. For example, radioastronomy gave us pulsars; x-ray astronomy has its flares and pulsating sources. Now it is the turn of gamma-ray astronomy. Ray Klebesadel, Ian Strong and Roy Olson (Los Alamos) recently reported¹ finding 16 short bursts of cosmic gamma radiation in three-years-worth of data from the Vela satellite program.

These observations were quickly confirmed by Thomas Cline and Upendra Desai (Goddard Space Flight Center), who reported their work with OGO and IMP satellites at the 13th International Cosmic Ray Conference held last August at the University of Denver. In October Cline, Desai, Klebesadel and Strong published² details on the energy spectra of some of the bursts, and the same four authors together with William Wheaton, Mel Ulmer, William Baity, Dayton Datlowe, Michael Elcan and Laurence Peterson (University of California, San Diego) published³ data on direction and spectral variability of one burst, obtained from OSO-7. And 40 papers on all aspects of the bursts, including several more observations by European and other US groups, were presented at the Conference on Transient Cosmic Gamma- and X-Ray Sources at Los Alamos in September.

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Cosmic gamma-ray burst, 14 May 1972. This event, shown here in data from the Vela satellite program, was also observed by IMP-6 and OSO-7 spacecraft. Note the multiple peaks near the onset of the burst. (From Ian B. Strong, Los Alamos Scientific Laboratory.)

Electron-hole droplets in germanium and silicon

When a new state of a well-known substance is found, enthusiasm spreads as theorists try to predict its properties and experimenters to verify its existence. This excitement has certainly followed the discovery of a condensed metallic phase in germanium and silicon. The apparent confirmation of conducting electron-hole "droplets" (about 1 micron in size) at temperatures of a few Kelvin is particularly good news for many-body theory because germanium and silicon are probably the best studied of all semiconductors and offer clean, simple systems for testing ideas.

The first reported hint of this conducting phase was J. R. Haynes's (Bell Labs) 1966 discovery¹ of a new lumines-

cence line from silicon subjected to low temperatures and powerful optical excitation. He interpreted the radiation as the decay of biexcitons—neutral molecules consisting of two electron-hole pairs—in analogy with the then well-known decay of one exciton, at higher energies. A few years later V. M. Asnin and A. A. Rogachev (Ioffe Institute, Leningrad) found² a sharp increase in the photoconductivity of germanium as they increased optical pumping power. L. V. Keldysh (Lebedev Institute, Moscow) then proposed³ that the phenomenon producing the jump in conductivity was the transition from a neutral excitonic gas to a metallic liquid. Subsequently the phenomenon

has been studied by several groups in the Soviet Union, most notably that of Ya. Pokrovskii and K. I. Svistanova⁴ (Institute of Radio Engineering and Electronics).

This metallic phase must be more stable than a molecular condensate of excitons under the same conditions. Calculations of the energy of the metallic state in the multivalley semiconductor have been done by William F. Brinkman and T. Maurice Rice (Bell Labs) and by M. Combescot and Philippe Nozières⁵ (Grenoble). P. Vashista, P. Battacharya and K. S. Singwi (Northwestern University) have pointed out⁶ that the correlations in the motions of electrons with holes in the condensed

phase may be sufficiently strong to cause condensation to occur even in semiconductors with more isotropic band structures. The equivalent of a simple Van der Waals model for the transition has been developed⁷ by R. N. Silver of Cal Tech.

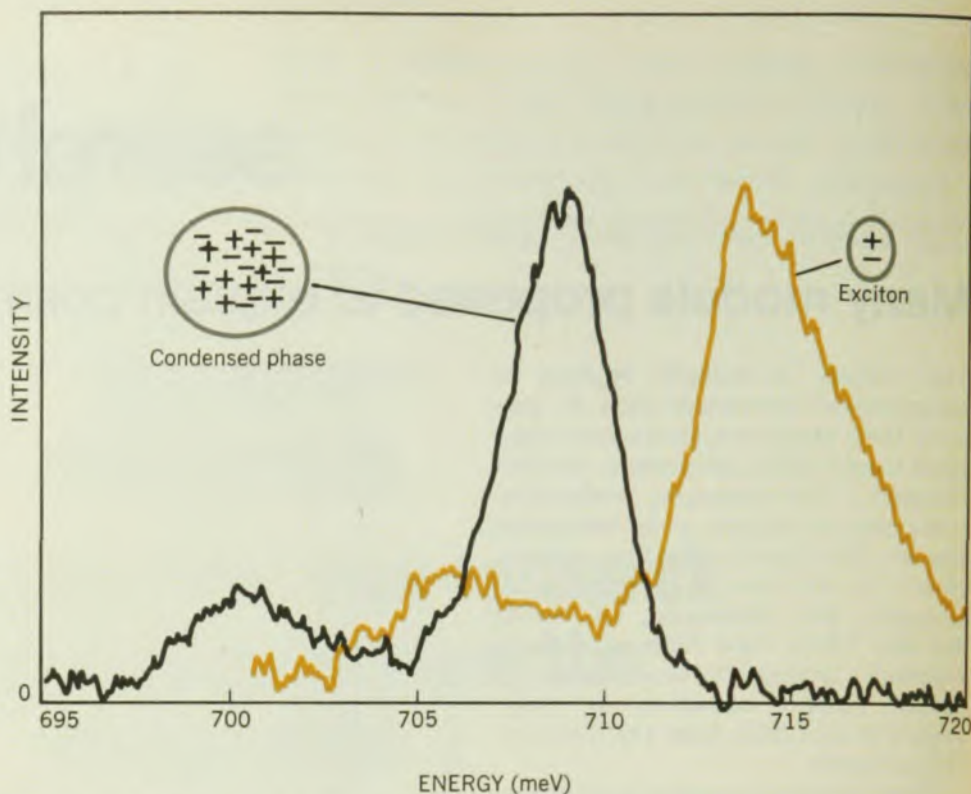
Experiments have concentrated on proving the existence of the droplet phase and, more recently, on measuring those quantities (such as condensation energy and the liquid-phase density) that theorists can calculate.

From Bell Laboratories, John Hensel, Thomas Phillips and Rice have reported⁸ a sharp temperature-dependent optical power threshold for the onset of a resonance decay signal from germanium. They aimed a pulsed 1.064-micron laser at a germanium sample kept in a liquid-helium bath. Cyclotron resonance, used to measure the decay, actually monitors free carriers. In the Bell Labs studies, the operating frequency was 53 GHz, much lower than the frequencies of the condensed phase, so that the observed signal is from free electrons outside the drop. As the experimenters explain, the free electrons result from the decay of the droplets, and the reported value for ϕ , the binding energy of the metallic liquid, is found to be about 16 K, in reasonable agreement with theoretical estimates.

In related work, the same group, together with Gordon A. Thomas, measured⁹ luminescence lines from germanium as a function of increasing temperature. They found a decrease in the natural linewidth with increasing temperature, implying a decrease in the number density of carriers. Their results are understandable for a system of droplets whose entropy increases linearly with temperature; that is, for metallic droplets. The constituents of these droplets obey Fermi statistics, and the compressibility of the electron-hole liquid largely determines the magnitude of the thermal expansion. In other words, the group notes, they have an experimental "handle" on the compressibility, in sharp contrast with the case for a single-component electron gas (as in a normal metal) whose compressibility is not experimentally accessible.

The early work on luminescence from electron-hole droplets was done by Pokrovskii and Svistanova and by Claude Benoit à la Guillaume, Michel Voos and F. Salvan¹⁰ of the Ecole Normale Supérieure (Paris). The work at the Ecole Normale has concentrated on spectroscopic determination of ϕ . The luminescence from the two phases of the phase-separated system, in other words the metallic liquid and the free exciton gas, is studied in detail and ϕ is determined to be 2.0 meV.

James McGroddy recently worked with Voos and Ove Christensen (Aarhus



Electron-hole droplets. High electron-hole concentrations in germanium are created near the surface by either laser or electron-beam excitation or in the volume by injection from n- and p-type contacts. At low electron-hole concentrations, exciton radiation (color) is seen. At high concentrations and low temperatures radiation characteristic of the condensed hole-electron phase is found (black). The shift in energy is one of many phenomena associated with the formation of the condensed phase. The spectra show the phonon-assisted recombination lines observed in carrier-injection experiments on germanium at 1.7 K by Marrello, Lee, Silver, McGill, Mayer and Hammond of Cal Tech.

University, Denmark) at IBM. They followed¹¹ the temperature dependence of the power needed to condense droplets. Excess shot noise produced by drops dissociating and collecting in a high electric field at a junction, as well as the 709-meV luminescence line caused by electron-hole recombination, were the two phenomena that indicated the presence of droplets. McGroddy stresses that these studies depend on properties of the drops themselves: Results are therefore less affected by departures from thermodynamic equilibrium than are techniques that monitor species (for example, free excitons or free electrons) related to droplets through the phase diagram. The value for ϕ found here is about 17 K. Analysis of the rate equations governing the system shows that the striking departures from equilibrium observed in this type of experiment below about 2 K are intimately related to the sensitivity of detection, that is, the minimum size drops observable. The cyclotron resonance method of Hensel, Phillips and Rice and the wide-band noise detection scheme used by McGroddy, Voos and Christensen appear to be far more sensitive in this respect than, for example, the luminescence methods, McGroddy told us.

Sharp optical pumping thresholds for luminescence in germanium at 709 meV and 714 meV have been observed by

Pokrovskii and by Thomas K. Lo, Bernard J. Feldman and C. D. Jeffries¹² (University of California, Berkeley). The Berkeley group is able to associate the 709-meV luminescence quite definitely with droplet formation and optical decay because it coincides with large electrical pulses in a junction on the same germanium crystal. And they find hysteresis in plots of the 709-meV and free exciton lines: This hysteresis, they point out, is characteristic of supersaturation in a gas-liquid transition. The Berkeley experiments also determine the binding energy ϕ to be about 18 K and establish a phase diagram for the free exciton gas-liquid drop system.

Droplets in most experiments so far have been produced by optical excitation or by a pulsed electron beam. At Cal Tech, electrical injection of electrons and holes from p- and n-doped semiconductors has now been used by V. Marrello, T. F. Lee, R. N. Silver, T. C. McGill, J. W. Mayer and R. B. Hammond to produce¹³ the condensed phase. Current pulses that lasted ten millisecc were used, and radiation characteristic of the condensed phase was observed. This radiation apparently came uniformly from the region between the contacts: that is, the condensed phase is present throughout the germanium sample. Most optical excitation studies have produced only surface excitation. Efforts now, McGill told us,

are to improve this excitation method to make a greater quantity of the condensed phase so that parameters of interest to theorists can be more conveniently studied. And, he notes, if the droplet phenomenon is eventually of technological importance, electrical excitation will be advantageous.

—*Marian S. Rothenberg*

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Fifty-two nations join in Geodynamics Project

The birth of the plate tectonics model of the earth has provided impetus for the Geodynamics Project, an international program under the auspices of the International Council of Scientific Unions. Fifty-two nations are participating in the project, which is planned for the period 1971-79 with the first three years to serve as a planning period.

US participation in the program will be guided by the Geodynamics Committee of the NAS, which has prepared a report with the help of hundreds of scientists and scores of institutions. Federal funding of \$50 million to come primarily from NSF and the US Geological Survey will serve to promote five major objectives:

- ▶ to develop further the basic model of plate tectonics,
- ▶ to test and demonstrate its ability to

explain and predict phenomena,

▶ to determine the degree to which it can be extended, its limitations in scale, in time and in the phenomena it will explain,

▶ to investigate whether apparently unrelated geodynamic phenomena are independent or are in some way related to the model, and

▶ to examine the implications of the findings with regard to basic and applied research.

Geodynamics, the study of the forces and processes in the earth's interior, will be studied under the international program with particular attention paid to the basic mechanism of earth deformations. Information from the study should help to solve economic and societal problems relating to the solid earth by providing answers for issues of interest to federal agencies and mining and petroleum industries.

Cosmic gamma rays

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The stored recordings of data from gamma-ray sensors on board Vela, OGO and IMP satellites, and from x-ray telescopes on OSO-7, contain evidence of occasional bursts of photons in the energy range 150-250 keV, most of duration about ten seconds. The appearance of the events correlates neither in time nor position with any other known astrophysical phenomenon. Theoretical speculation runs through a gamut of models including shock waves in supernovae, stellar flares, collapsing neutron stars, comet capture by neutron stars, and many others. Interest in these bursts, as in the other transient astronomical observations, derives from the clues they could give to an understanding of the mechanism of the highest-energy processes in astrophysics—those associated with the final cataclysmic stages in stellar evolution.

Observations. About 20 gamma-ray bursts have now been identified in searches of records going back to 1967 data, giving an estimated rate of about four events per year over the whole sky. Coincidences among independent satellite observations serve to distinguish "good" data from noise and instrumental effects—only those events seen by two or more satellites simultaneously have been counted. This is all "archaeological" data, as Cline pointed out to *PHYSICS TODAY*. He believes that most of the old data are in now, and only occasional reports of new events are to be expected from currently orbiting satellite instrumentation.

The Vela series of satellites monitors the limited nuclear test-ban treaty of 1963; their sensitivity to short-term photon flashes in the gamma region

would, for example, detect bombs detonated behind the moon. Stirling Colgate (New Mexico Institute of Mining and Technology), a Los Alamos consultant, realized that this system would also be sensitive to gamma bursts that he and others believed would be released by supernovae. However, searches of early Vela data near the times of appearance of supernovae met with no success. Later Vela satellites, those numbered 5A, 5B, 6A and 6B, possess improved instrumentation, which allows short-time-scale phenomena to be more easily dug out of the old records, and much more accurate (± 0.016 sec) event timing. These four spacecraft (in orbit simultaneously) successfully detected 16 events in the period July 1969 to July 1972 that satisfied the criterion of simultaneous observation.

Vela detectors are omnidirectional, but comparison of the arrival times of a burst of photons at each satellite gives enough angular resolution to rule out the sun as the source of most of the observed bursts. There is no energy resolution in Vela data; the energy window for the detectors is 0.2-1.0 MeV (Vela 5) and 0.3-1.5 MeV (Vela 6).

News of these gamma-ray bursts set off a flurry of excitement in other groups holding similar data. At the NASA Goddard Space Flight Center, Cline and Desai were able to find one of the Vela events in their 1969 data from OGO-3 and had already independently extracted six more from the 1971-72 period in data from the IMP-6 satellite. These IMP-6 data provided direct evidence that the signals are produced by gamma rays and not charged particles or neutrons. Detectors on board OGO-3 and IMP-6 are omnidirectional, like the ones on the Vela satellites, but IMP-6 gives energy spectra not available from Vela.

The most complete observation available to date is of a burst that occurred 14 May 1972 (see figure). This one, as well as being observed by three Vela satellites and the IMP-6, fell within the scan path of the x-ray telescopes on board OSO-7. With these instruments (narrow-angle cosmic x-ray telescope and wide-angle solar x-ray telescope operated by the University of California, San Diego) unambiguous determination of the direction of the burst and time-dependent energy spectra were available for the first time.

Five of the events were seen by Uhuru, American Science and Engineering's x-ray satellite, and reported at the Los Alamos meeting by David Koch. Uhuru's collimators, effective in the 2-20 keV range, did not screen out the higher-energy gamma radiation, which produced Compton elec-